Restoration of images from an airborne unstabilized hyperspectral line scanner

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ABSTRACT

An airborne hyperspectral line scanner is used to image the ground as the aircraft moves on a single trajectory. In reality, it may be difficult for the aircraft to maintain a perfectly steady course causing distortions in the imagery. So, special subsystems including stabilizers are used to maintain the hyperspectral line scanner on the proper course. If the subsystems of an airborne hyperspectral line scanner are malfunctioning or if the proper stabilizers are not available, then a technique is needed to restore the imagery. If no stabilizers are used on the airborne line scanner, but if aircraft navigation information is available including yaw, pitch and roll, then the restoration may be automated. However, if the stabilizers are malfunctioning or if the navigation information is corrupted or unavailable, then a technique is needed to restore the imagery. This paper introduces an automated technique for restoring hyperspectral images that was used on some images obtained for the Dynamic Data Base (DDB) program sponsored by the Defense Advanced Research Projects Agency (DARPA). The automated approach is based on image flow vectors obtained from the unstable image. The approach is introduced along with results that demonstrate how successful the restoration is at the feature level.

Keywords: Hyperspectral, Algorithm, Image Restoration, Motion Compensation

1. INTRODUCTION

The Dynamic Database (DDB) progam sponsored by the Defense Advanced Research Projects Agency (DARPA) involves exploitation of multiple sensor types, including imaging, signal intelligence and moving target indication (MTI) for the purposes of developing a situation estimate on the battlefield as depicted in Figure 1. In support of the development of these technologies, a multisensor data collection was conducted at Eglin Air Force Base which included high spatial resolution EO, IR, SAR and high spectral resolution hyperspectral imaging sensors.

The Hyperspectral Imager, TRWIS, provides spectral coverage from 370-2500 nm and was developed by TRW. The system has two separate optical paths, one associated with the visible-near infrared (VNIR) and one associated with the short wave infrared. The VNIR system collects data from 370-1010 nm using 128 bands where the spectral width of each band is 5nm. The SWIR data is collected with 256 bands ranging from 900-2500 nm with a 6.25nm bandwidth. The IFOV for the VNIR portion of the sensor is .882 mrad while the IFOV for the SWIR portion is .886 mrad. The cross track FOV for both sensors is 13.1. There are 256 cross track pixels collected in a pushbroom scan format. Data for all bands is 12-bit. The frame rate (sample rate) of the sensor is 60 Hz at 3000 ft in altitude and 30 Hz and 6000 ft in altitude. The calculated resolution of the TRWIS sensor is 2.7 ft at a 3000 ft altitude and 5.4 ft at a 6000 ft altitude. Figure 2 shows a collected spectral cube as well as a distribution format.

This hyperspectral sensor was hard mounted on light fixed wing aircraft, resulting in significant image spatial distortions in some of the imagery due to aircraft instabilities which in many cases are not known due to INS problems aboard the aircraft during the collection. With the hyperspectral scanner pointed to nadir, the predominant error that was most noticeable in the imagery was the motion error due to roll. The compensation algorithm presented in this paper compensates for the roll by tracking the image flow. The special consideration needed for hyperspectral imagery is finding an appropriate band or combination of bands for determining image flow. As will be shown, the image flow was found to be easier to obtain with specific bands.

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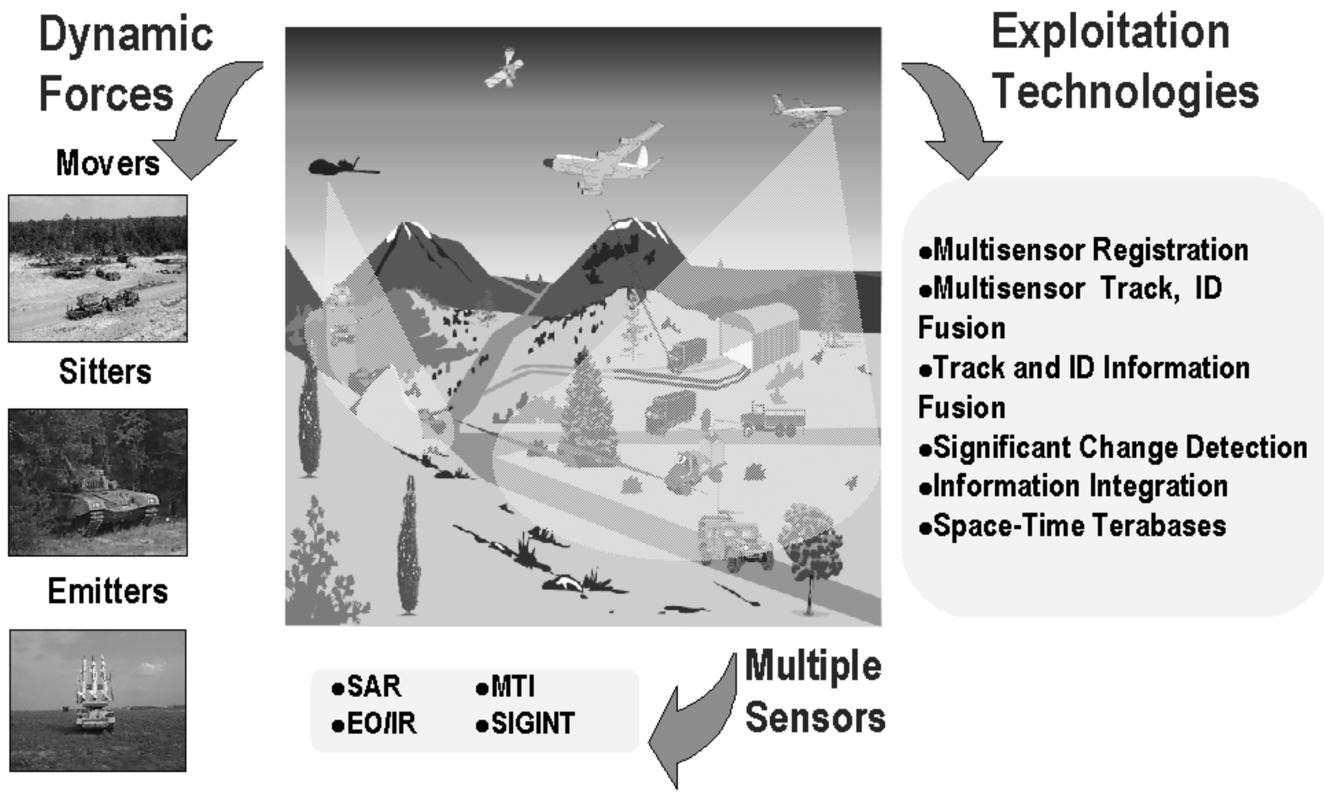

Figure 1. Dynamic Database (DDB) Overview.

2. SEMI-AUTOMATED ROLL COMPENSATION

For a line scanner looking nadir, roll predominantly causes a side-to-side shift which looks like a wavy distortion in the final image produced by a line scanner. Our initial attempt at restoration involves a semi-automated approach using an analyst. In this approach, the analyst chooses a band in which the motion distortions are evident. Then, while observing the image on a monitor, the analyst uses a mouse to draw a curve on the image. This curve estimates the side-to-side image shift. Using the curve drawn by the analyst, the computer applies an inverse model and displays the restored image. However, the first attempt by the analyst to visually determine the side-to-side shift in the image is not necessarily successful. Therefore, multiple refinement steps are needed. The refinement step is the same as the initial step and is repeated until the image appears visually correct. The computer program generates the curve required to compensate the image and then applies the inverse model of the curve across all bands in the hyperspectral image. This process appears to work adequately but is very time consuming and impractical for large volumes of data. Therefore, we have developed an automated approach to restoring the hyperspectral imagery.

3. IMAGE FLOW

This section introduces the concept of image flow for a single image frame. Image flow or optical flow in literature[1,2] typically involves multiple two-dimensional images and three variables of which two variables account for space and one variable accounts for time. In the case of a single image created by a line scanner, the image is typically thought to be a two variable image based on the spatial dimensions. Since, there is no temporal dimension, the application of optical flow is not applied. However, if one thinks of the line scanner image as having one variable for space and one variable for time, then optical flow can apply. Optical flow is easy to consider if one thinks of each line scan as a one-dimensional image collected sequentially in time. Another consideration that is needed in order to calculate image flow is an assumption that a single point of intensity $I(x,t)$ does not change in intensity but does change in position. Therefore, the position x varies by t and

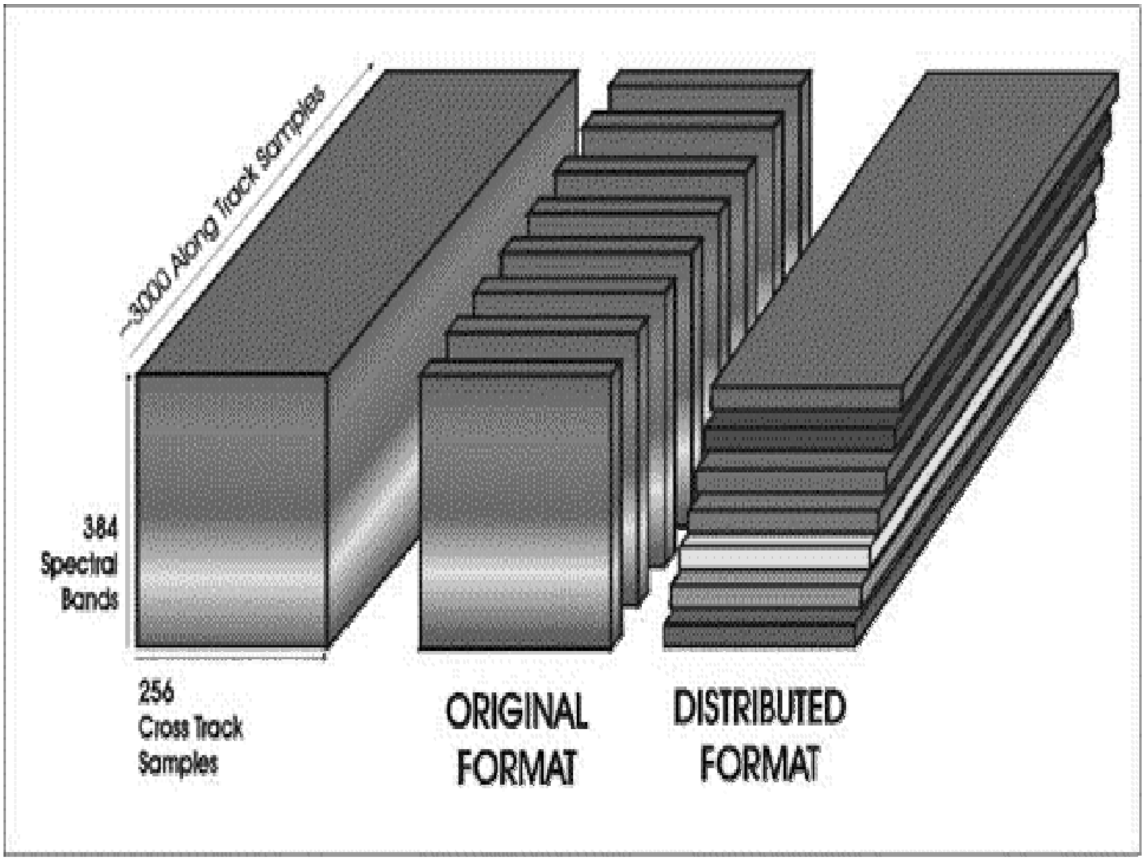

Figure 2. Hyperspectral Imager (HSI) Spectral Cube Formats.

$$\frac{dI(x,t)}{dt} = 0. \tag{1}$$

Using the chain rule of differentiation, Equation 1 can be written as

$$\frac{\partial I(x,t)}{\partial x} v(x,t) + \frac{\partial I(x,t)}{\partial t} = 0 \tag{2}$$

in which $v(x,t)$ is the image flow at a single point which is defined as

$$v(x,t) = \frac{dx}{dt}. \tag{3}$$

Rearranging Equation 2 yields a new equation for image flow as

$$v(x,t) = \frac{-\partial I(x,t)/\partial t}{\partial I(x,t)/\partial x}. \tag{4}$$

Over a single line of length x_{max}, the line can be thought of as shifting a distance V represented as

$$V = \frac{1}{x_{max}} \int_0^{x_{max}} v(x,t)dx. \tag{5}$$

This shift is one way to measure the image flow for a line scanner. These equations provide a good starting point for explaining the concept behind determining the shift in the image. However, for gradient approaches the individual

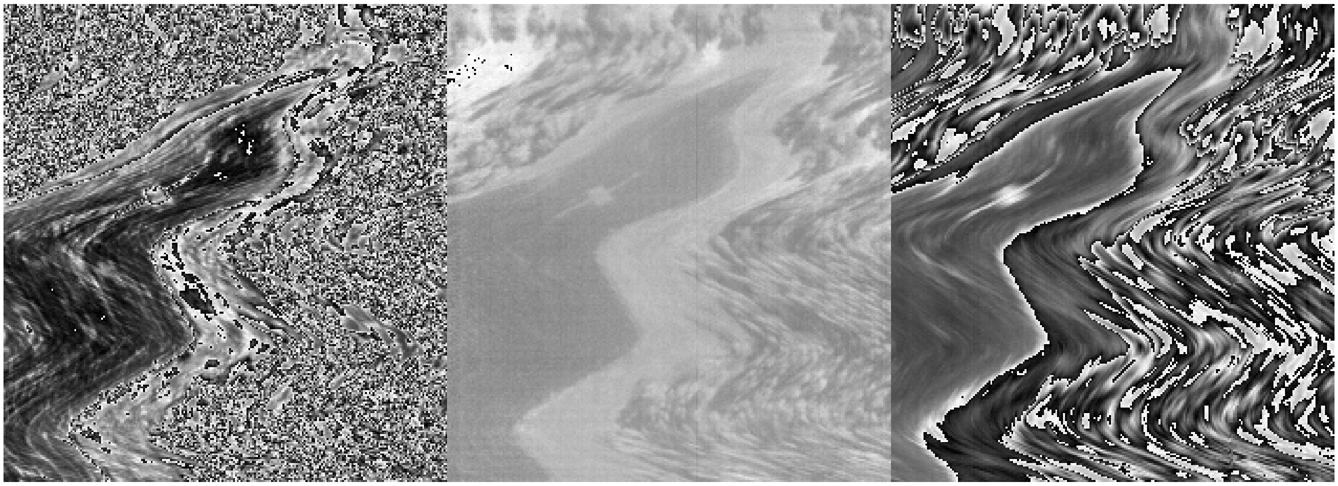

Figure 3. Three spectra of a hyperspectral image suffering from uncompensated motion. From left to right, the spectra are at bands 70, 127 and 255. At the feature level, the predominant error appears to be side-to-side shifts.

shifts of each pixel are not picked up well for certain areas of continuous intensity. Therefore, the true shift of each pixel may be skewed. A modified approach is to look at how a scan line shifts by determining the shift that maximizes the cross-correlation between adjacent lines. If, as described above, $I(x,t)$ or its discrete counterpart $I(x_n,t_n)$ is assumed to be a constant intensity as it moves through time, then a cross-correlation, $R(v)$ should be maximum when adjacent scan lines are aligned in such a way as to match up the constant intensities. Therefore, the shifting distance V is the shifting value v that maximizes

$$R(v) = \frac{1}{x_{max}} \sum_{x_n=1}^{x_{max}} I(x_n,t_n) I(x_{n+v}, t_n+1). \tag{6}$$

4. AUTOMATED ROLL COMPENSATION

The automated approach to roll compensation is a multi-step process. For hyperspectral, the first step is to find an appropriate band to obtain the image flow. The second step is to calculate the image flow based on the one band chosen. The third step is to apply an inverse image flow model to the image to obtain the restoration. This process is demonstrated using the hyperspectral image with uncompensated motion shown in Figure 3. This figure shows three of the 384 bands collected which demonstrates that the motion distortion is independent of the band. However, the application of the routine to automatically restore the images is dependent on which band is chosen for calculating the image flow. Figure 4 demonstrates a restoration attempt using band 127 to calculate the image flow while Figure 5 demonstrates a better restoration attempt using band 255. The image flow pixel shifts for band 127 and band 255 is shown in Figures 6 and 7 respectively.

The criteria we used for selecting a proper band for restoration is based on the highest value obtained from two measures. The first measure is the mean correlation peak between scan lines. The mean correlation peak for a band can be obtained by averaging the results obtained from finding the maximum peaks using Equation 6. The second measure is the mean differential in the top two correlation peaks. The differential is the difference between a cross-correlation peak and the next higher cross-correlation peak. Results for bands 70, 127, and 255 are shown in Figure 8. For this particular flight, band 255, shows a higher difference between the top two cross-correlation peaks for adjacent scan lines. The mean peak values and the mean peak difference value is shown in Table 1. A higher peak difference in Table 1 reflects a higher confidence in the correlation of two adjacent lines.

Figure 4. The result of using the wrong band to restore the three spectra of a hyperspectral image suffering from uncompensated motion.

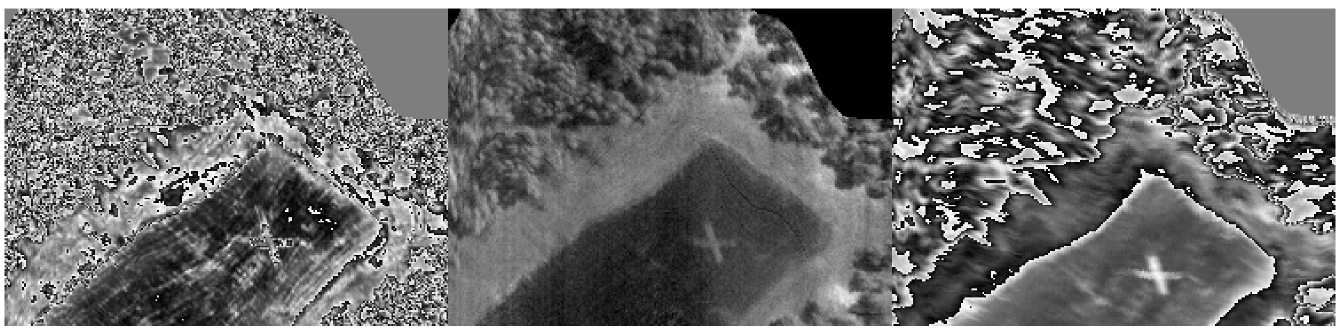

Figure 5. Three spectra of a hyperspectral image after restoral of the side-to-side shifts.

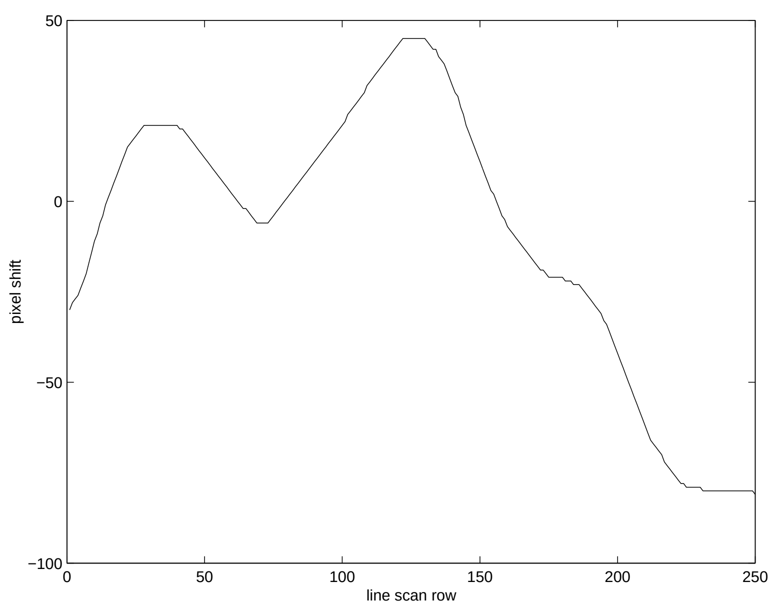

Figure 6. The image flow pixel shifts for proper restoration of 250 line scan rows. For each line scan row, the pixel shifts represent the number of pixels the line scan row is shifted from the first line scan row.

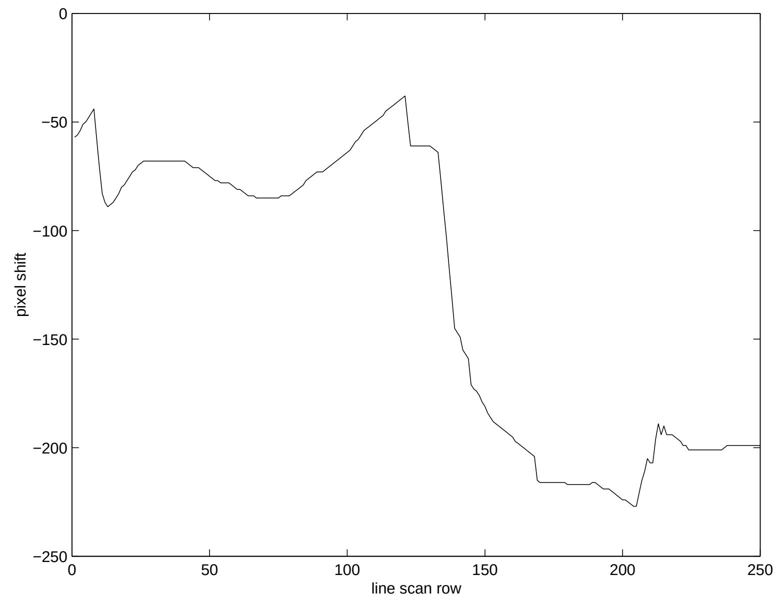

Figure 7. The image flow pixel shifts for improper restoration of 250 line scan rows due to poor band selection.

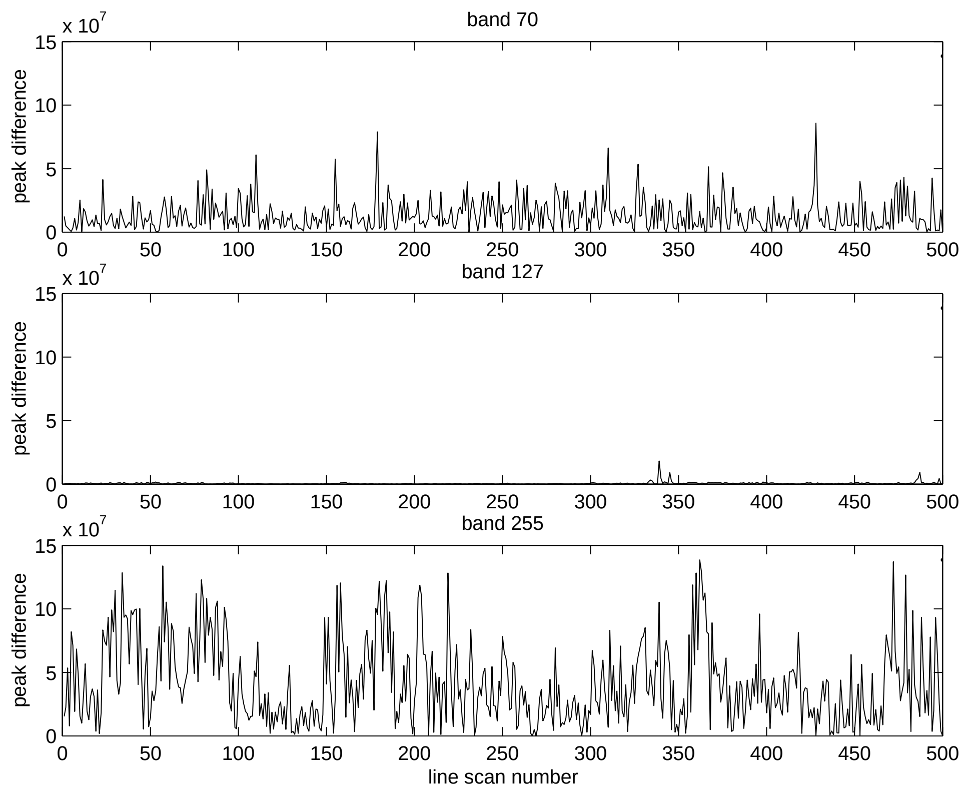

Figure 8. The difference between the highest cross-correlation peak and the next higher cross-correlation peak for spectra in bands 70, 127, and 255. For this particular flight, band 255, shows a higher difference between the top two cross-correlation peaks.

5. CONCLUSION AND FUTURE RESEARCH

This paper introduces techniques for restoring hyperspectral imagery that suffers from uncompensated motion. The concept of image flow for a single image is introduced. The image flow is obtained for an image created from a line scanner. The paper demonstrates that image flow is easier to determine for certain bands. The bands needed for determining image flow are hypothesized to have statistical properties that make possible the automation of band selection.

This proposed off-line software-based motion compensation approach is not meant to replace an airborne onboard hardware stabilizer. One advantage for the onboard hardware system is that it can prevent blank spots in the imagery such as is evident in the restored image shown in Figure 5. However, the software-based system is found to be useful when the hardware fails, the navigation data is inoperative, and for a test system not wanting to fund or put the effort into adding stabilization hardware.

One of the goals for future research is to examine the impact of yaw and pitch on the imagery to allow for a complete system that can provide an automated software-based stabilizer. Additionally, future research may seek to determine if there is any advantage for using multiple bands or combinations of bands to obtain the image flow.

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Cross-Correlation Statistics for Selected Hyperspectral Bands			
Band	Wavelength (nm)	Mean Peak Value	Mean Peak Difference
70	715	0.9404e+008	1.3128e+007
127	1000	2.0327e+008	0.0569e+007
255	1687.5	2.1176e+008	4.1580e+007

Table 1. A comparison of the mean cross-correlation peak value and the mean peak difference. The peak difference is the difference between the top two cross-correlation peaks between adjacent scan lines.